Laboratory Evaluation AirBeam $PM_{2.5}$ Sensor

South Coast AQMD

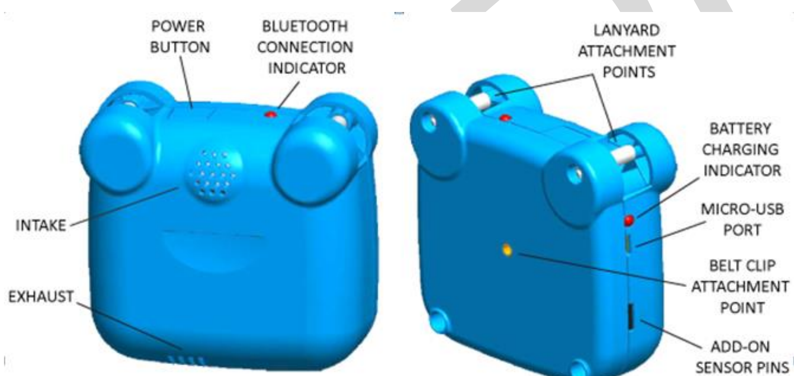
AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Background

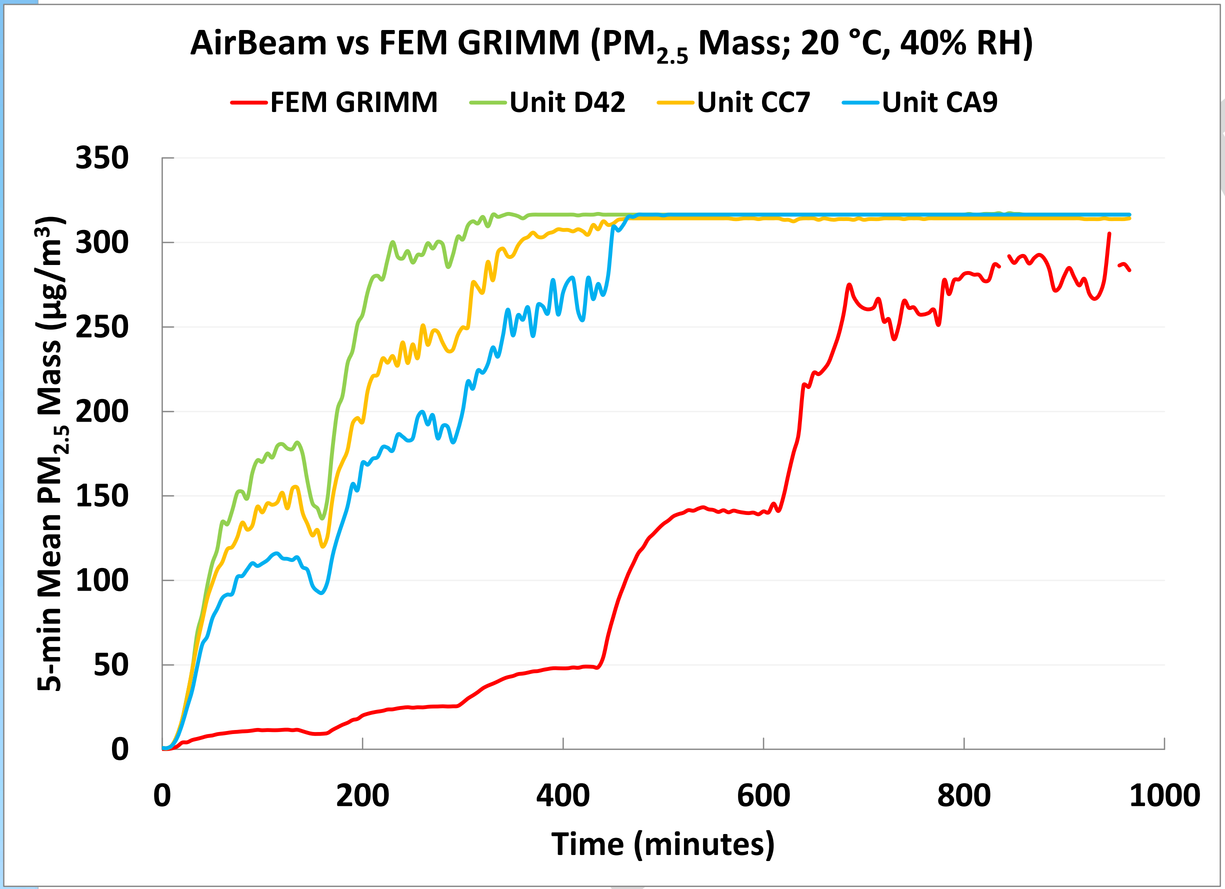
- Three **AirBeam** PM Sensors that were previously field-tested at the SCAQMD Rubidoux fixed air monitoring station (deployment period: 04/30/2015 to 06/19/2015) under ambient weather conditions, have now been evaluated in the SCAQMD Chemistry Laboratory under controlled PM concentration, temperature and relative humidity.

- AirBeam Sensor (*3 units tested*):
  - Particle sensors (optical; non-FEM)
  - Each unit measures: $PM_{2.5}$ mass ($\mu g/m^3$) and $PM_{2.5}$ count (hundred particles/ft^3)
  - Unit cost: ~$200
  - Time resolution: 1-min
  - Firmware: March 2015 AirBeam firmware
  - Units IDs: D42, CC7, CA9

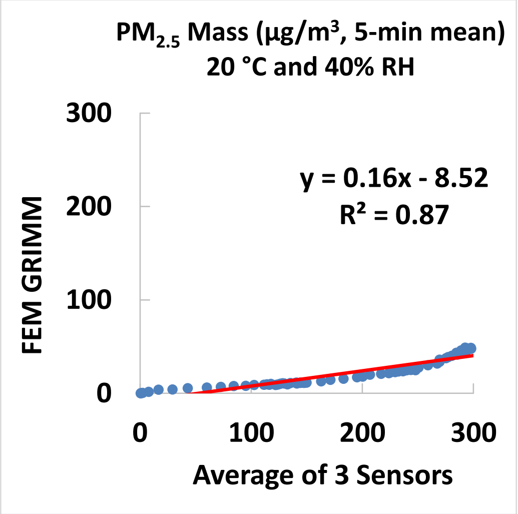
- GRIMM (*reference method*):
  - Optical particle counter
  - FEM $PM_{2.5}$
  - Uses proprietary algorithms to calculate total PM, $PM_{2.5}$, and PM_1 mass conc. from particle number measurements
  - Cost: ~$25,000
  - Time resolution: 1 min



AirBeam vs FEM GRIMM ($PM_{2.5}$ mass; 5-min mean)



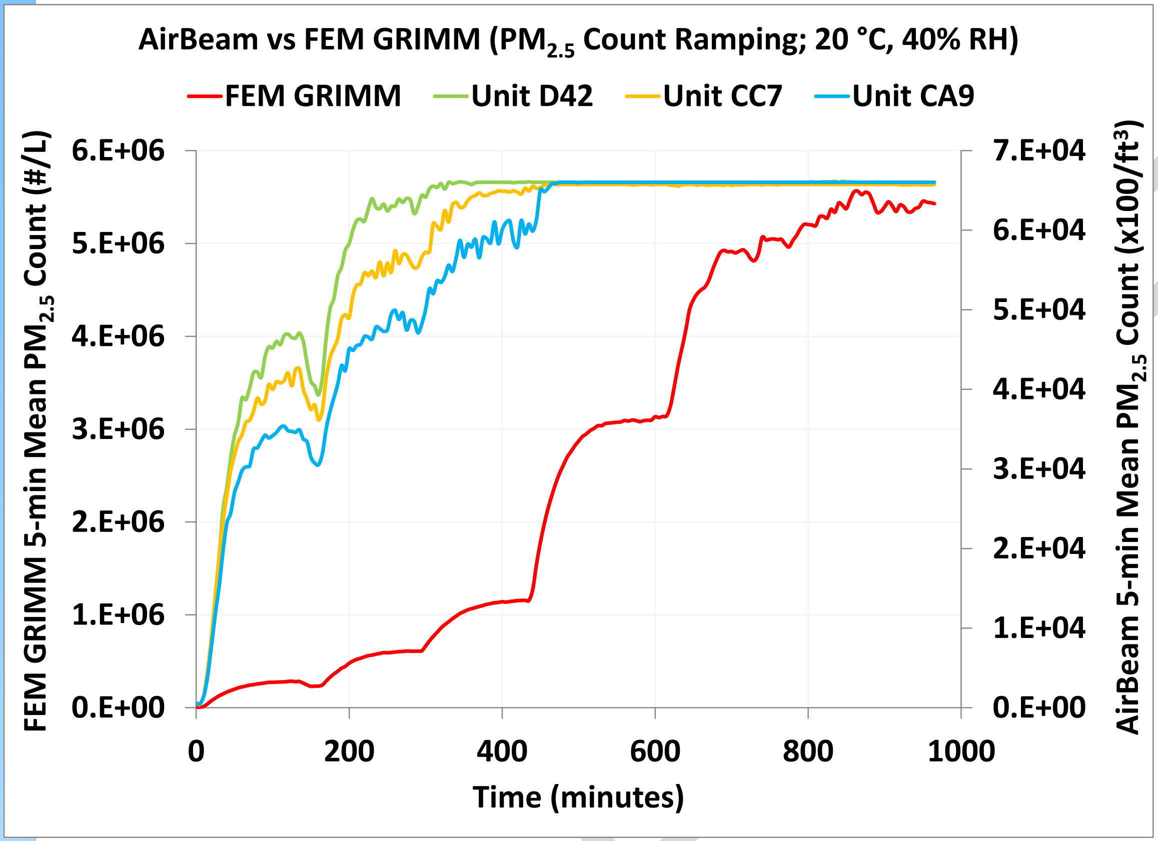
Linearity of sensor response



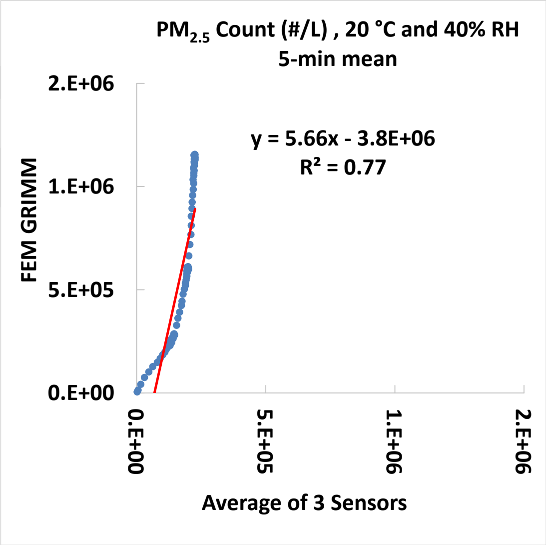
- AirBeam sensors showed good correlation with GRIMM $PM_{2.5}$ measurement data (R^2~0.87) when GRIMM $PM_{2.5}$ was lower than 50 μg/m³. However, the AirBeam sensors largely overestimated (> 5 times) the GRIMM $PM_{2.5}$ (slope = 0.16 and intercept = -8.51).

- When GRIMM $PM_{2.5}$ concentration was less than 50 μg/m³, the AirBeam sensors tracked well with $PM_{2.5}$ (μg/m³) variations (concentration ramping) recorded by the GRIMM.
- The AirBeam sensors reached their maximum $PM_{2.5}$ reading of about 300 μg/m³ when GRIMM $PM_{2.5}$ exceeded 50 μg/m³.
- The GRIMM showed very low measurement variability at low $PM_{2.5}$ concentration compared to the AirBeam sensors.

AirBeam vs FEM GRIMM ($PM_{2.5}$ count; 5-min mean)



Linearity of sensor response



- AirBeam sensors showed good correlation with GRIMM $PM_{2.5}$ measurement data (R^2~0.76) when GRIMM $PM_{2.5}$ count was lower than $2.0*10^6$ #/L. However, the AirBeam sensors significantly underestimated (about 80% less) the GRIMM $PM_{2.5}$ (slope = 5.66 and intercept = $-3.8*10^6$).

- When GRIMM $PM_{2.5}$ count was less than $2.0*10^6$ #/L, the AirBeam sensors tracked well with $PM_{2.5}$ (#/L) diurnal variations (concentration ramping) recorded by the GRIMM.
- The Airbeam sensors reached their maximum $PM_{2.5}$ reading of about $6.5*10^4$ ($x100/ft^3$) when GRIMM $PM_{2.5}$ exceeded $1.0*10^6$ #/L.
- The GRIMM showed very low measurement variability at low $PM_{2.5}$ count compared to the AirBeam sensors.

AirBeam $PM_{2.5}$ mass accuracy

- Accuracy (20 °C and 40% RH)

Steady State (#)	Sensor mean (µg/m^3)	FEM GRIMM (µg/m^3)	Accuracy (%)
1	147.9	11.5	-1086
2	243	25.4	-757
3	296.2	48.7	-408

- Overall, the three AirBeam sensors showed very low accuracy compared to FEM GRIMM at 20 °C and 40% RH, when varying $PM_{2.5}$ mass concentration from 10 to 50 µg/m^3. The AirBeam significantly overestimated the FEM GRIMM readings. According to the method of calculating accuracy, the %accuracy for the sensors were all negative. When $PM_{2.5}$ mass conc. was over 50 µg/m^3, AirBeam sensors reached a plateau of 315 µg/m^3.

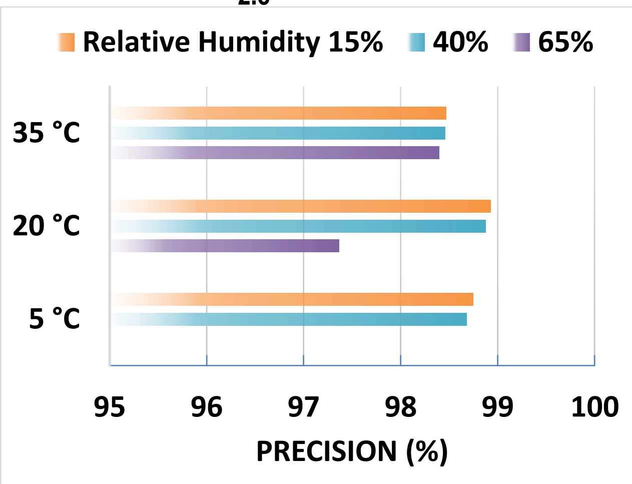
AirBeam data recovery & intra-model variability & LDL

- Data recovery for $PM_{2.5}$ from all three AirBeam units was 100%.
- Substantial intra-model variability (45%) was observed between the three AirBeam sensors at low $PM_{2.5}$ concentration (measured by GRIMM) at 20 °C and 40% RH. When the $PM_{2.5}$ concentration measured by the GRIMM exceeded 50 µg/m^3, the AirBeam sensors quickly reached their maximum of 300 µg/m^3, and they stopped responding to any further concentration increase. Thus, intra-model variability for medium and high $PM_{2.5}$ concentration could not be estimated.
- AirBeam sensors' LDL were close to 0 µg/m^3.

AirBeam vs FEM GRIMM ($PM_{2.5}$; 5-min mean)

- Precision (Low $PM_{2.5}$ conc.,and various Temperature and Relative Humidity)

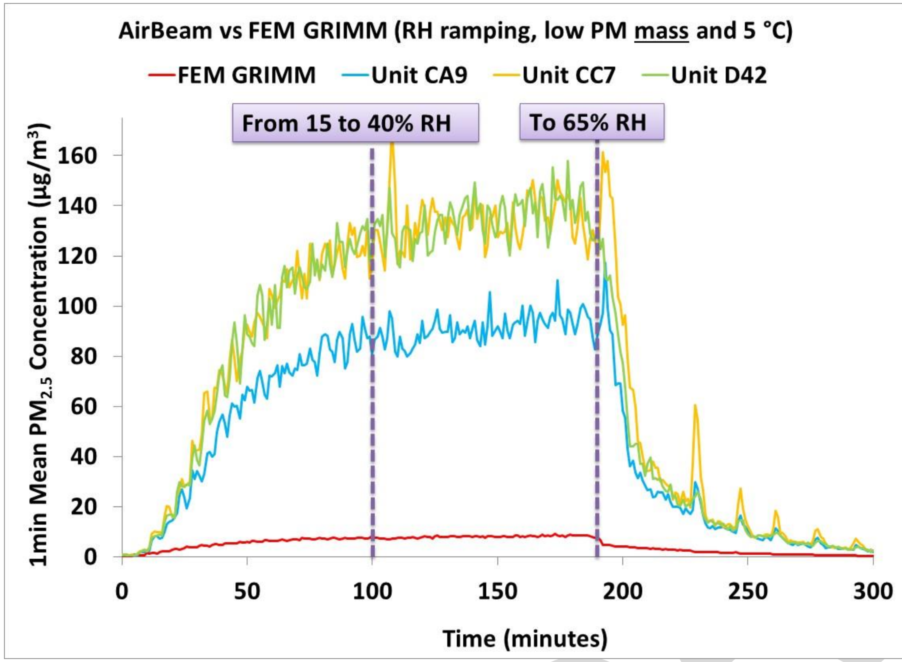
Low $PM_{2.5}$ Concentration



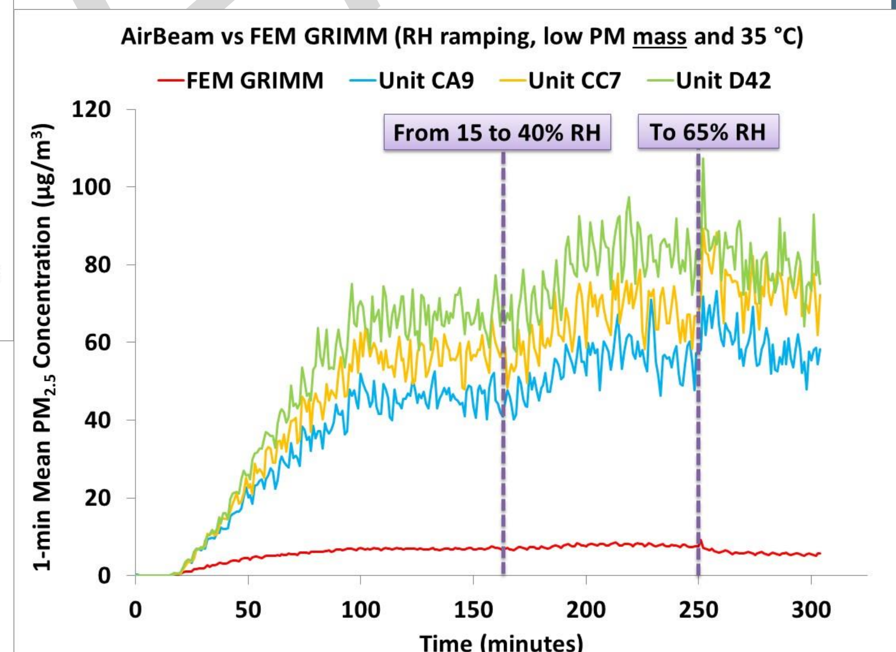
Precision could not be estimated at medium to high $PM_{2.5}$ concentration; at least one of the three AirBeam sensors reached the maximum $PM_{2.5}$ it could measure.

- Overall, the three AirBeam sensors showed good precision for almost all combinations of T and RH at low $PM_{2.5}$ concentration.
- At medium to high GRIMM $PM_{2.5}$, sensors' precision could not be estimated, because the sensors were only reporting their maximum measurement value of 300 µg/m^3.
- FEM GRIMM precision was very high across all conditions.

AirBeam $PM_{2.5}$ Climate Susceptibility



Low Temp – RH ramping
(medium conc.)



High Temp – RH ramping
(low conc.)

Discussion

- **Accuracy**: Overall, the three AirBeam sensors showed very low accuracy compared to FEM GRIMM at 20 °C and 40% RH, when varying $PM_{2.5}$ mass concentration from 10 to 50 µg/m^3. The AirBeam sensors significantly overestimated the FEM GRIMM readings. According to the method of calculating accuracy, the %accuracy for the sensors were all negative. When $PM_{2.5}$ mass conc. was over 50 µg/m^3, Airbeam sensors reached plateau of 315 µg/m^3. (refer to slides 3, 4, and 5)
- **Precision**: Overall, the three AirBeam sensors showed good precision for almost all combinations of T and RH at low $PM_{2.5}$ concentration. At moderate to high GRIMM $PM_{2.5}$, sensors' precision could not be estimated, because the sensors were only reporting their maximum value of 300 µg/m^3. (refer to slide 6)
- **Data recovery:** Data recovery for $PM_{2.5}$ from all three AirBeam units was 100%.
- **Linearity of sensor response**: AirBeam sensors showed good correlation/linear response with the corresponding FEM GRIMM $PM_{2.5}$ measurement data ($R^2 \sim 0.87$) for mass concentrations below 50 µg/m^3 (refer to slides 3 and 4)
- **Lower detection limit (LDL)**: AirBeam sensors' LDL was close to 0 µg/m^3.
- **Climate susceptibility**: From the laboratory studies, temperature and relative humidity had little effect on the sensor performance at low GRIMM $PM_{2.5}$. However, at high $PM_{2.5}$ concentrations, sensors failed to respond to the diurnal variations and all reached their maximum output reading of about 300 µg/m^3, therefore, the effect under those conditions could not be studied. (refer to slide 7)